THE American Surveyor

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Summer 2006

New Technology

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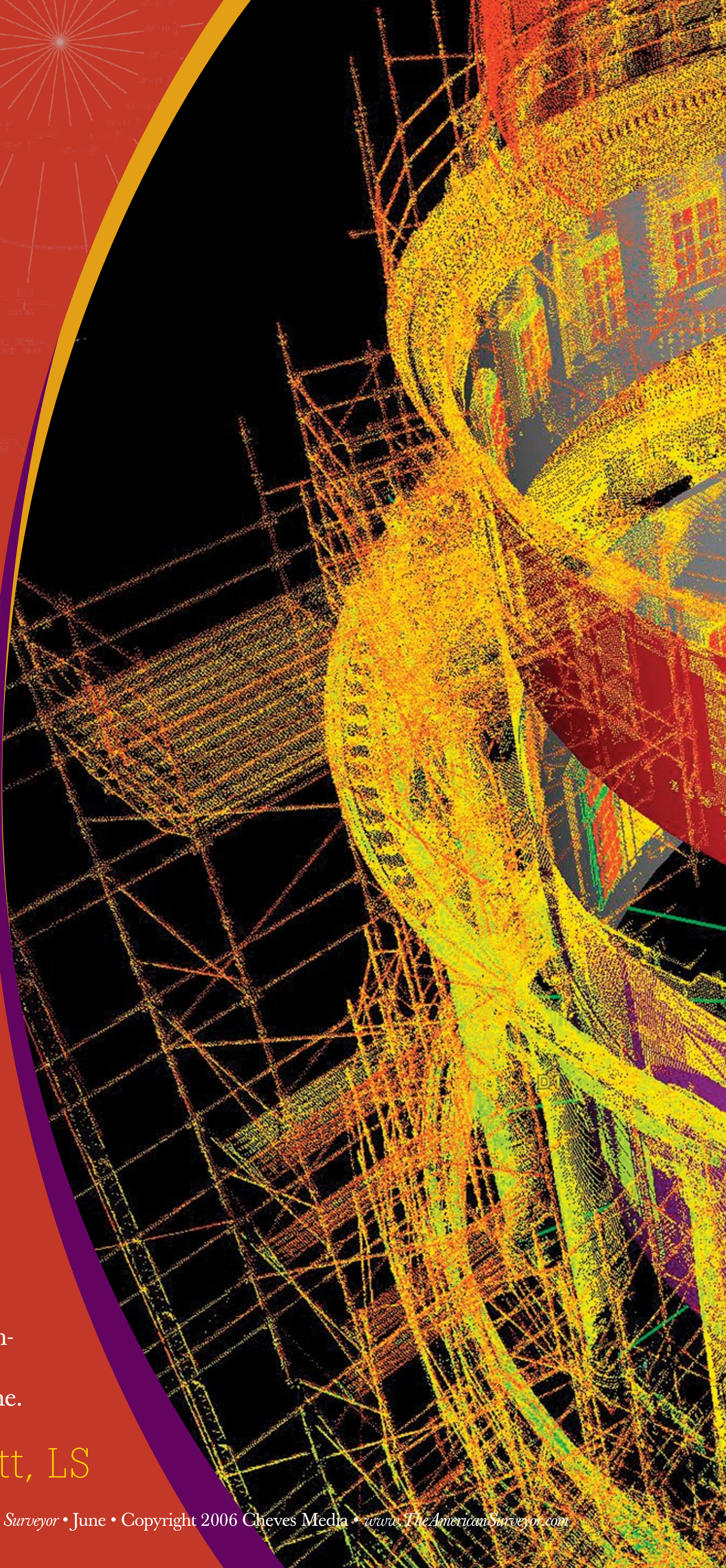
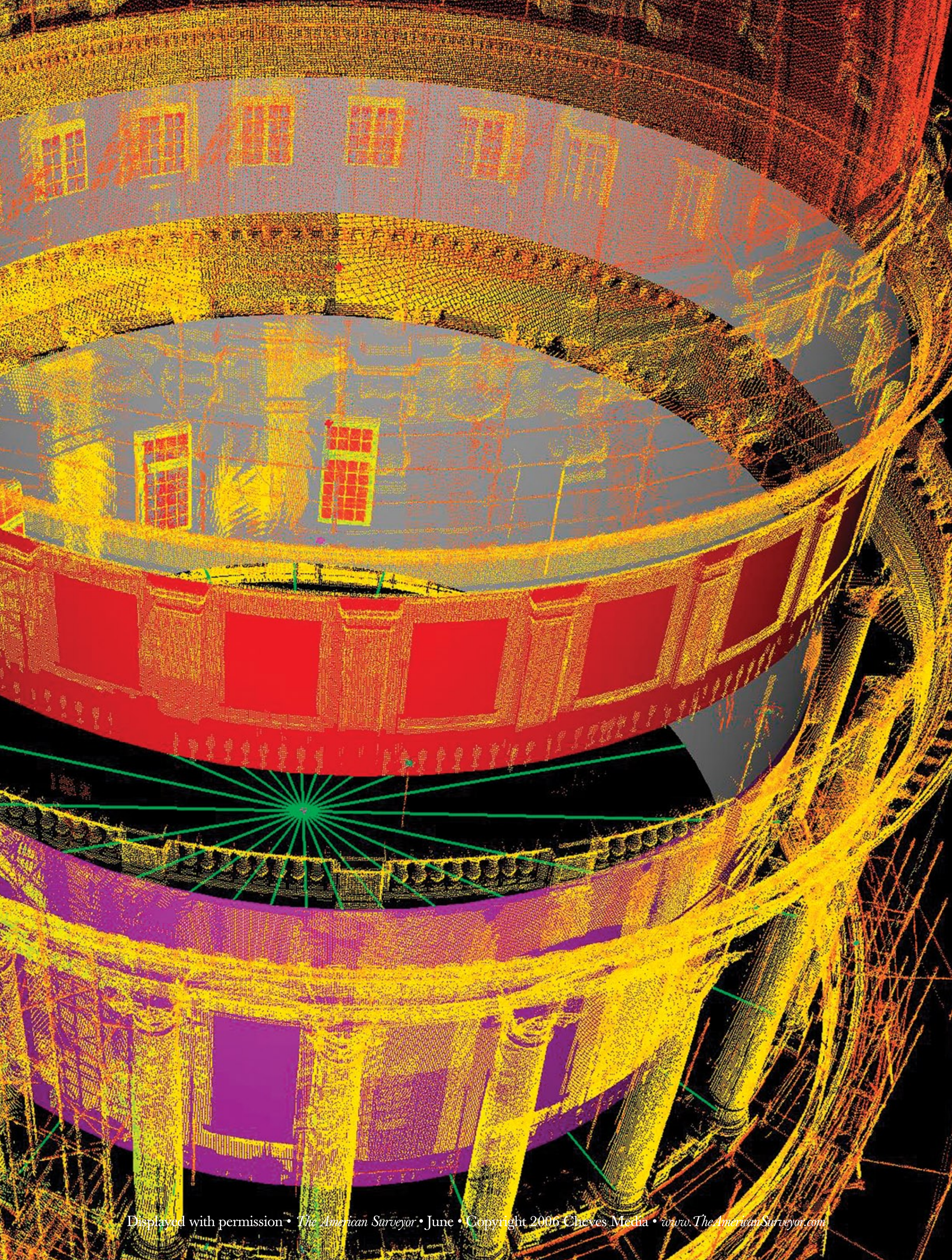
Practical GPS Network
A case study for justification

Surveying at the Utah State Capitol Dome



It was a dark November evening; it was snowing, and our survey crew was more than 200-feet in the air atop the Utah State Capitol Dome, freezing. David Evans and Associates, Inc. (DEA) had been contracted to provide as-built drawings for the restoration of the historic capitol dome. This task presented several challenges ranging from how to meet the accuracy requirements and tight schedule to how to collect and convey the data in a useful format. DEA responded by using a combination of laser scanning and conventional survey methods to provide highly accurate and easily usable data on a tight timeline.

>> By Sean Douthett, LS



The Utah State Capitol is a beautiful 285-foot-tall building, located on a hill overlooking downtown Salt Lake City. The original groundbreaking took place in 1912, and the 400-foot long by 240-foot wide building was completed and dedicated in 1916.

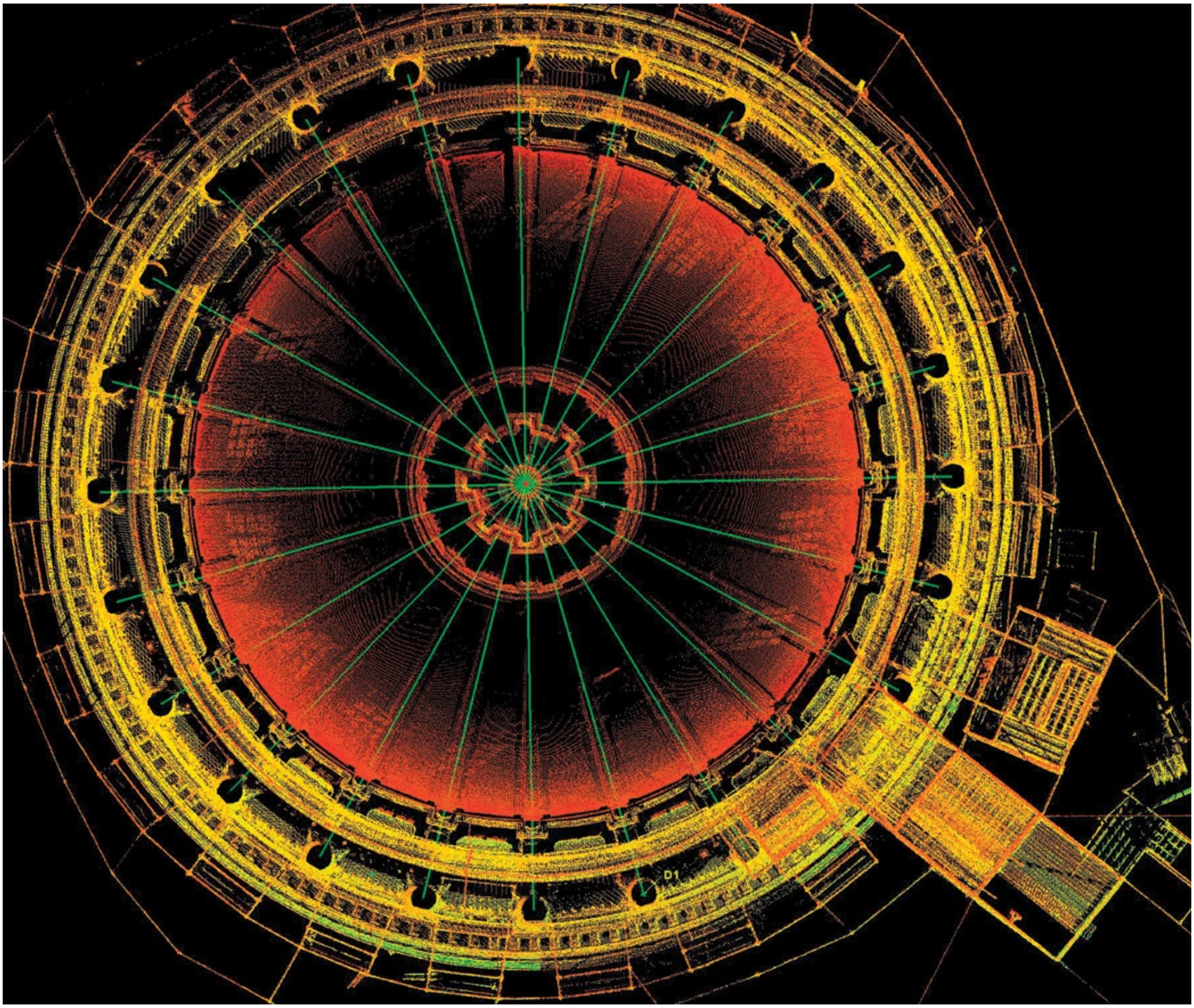
The architect's design called for the best workmanship, the finest materials, the most up-to-date design standards available, and was to be constructed for less than $3 million. Specifications called for the building to be sided with fine granite and terra-cotta tiling, but by the time the construction crews had worked their way up to the drum, money was running low and corners had to be cut. The contractor's solution was to use a less-expensive terra-cotta colored plaster on the upper and lower drums, rather than the tiling. They added grout lines to the plaster so that from the ground one could not see much, if any, difference.

In May of 2002, the Utah State Capitol Preservation Board broke ground to begin the comprehensive restoration and construction of the Capitol campus. This renovation will take the building back to its original look but with features that will allow it to function as a 21st century office building. The current work at the Capitol has a budget of $200 million, and includes constructing two additional buildings planned for in the original architect's design, seismic base isolation, and re-facing the drum with the terra-cotta tiles as was originally planned. This project is scheduled to be completed in 2008.

The state selected KEPCO+ Architectural Cladding Systems to, among other things, tile the drums, and replace the existing columns and decorative railings around the drum. KEPCO+ planned to engineer a prefabricated panel system which would allow 65 percent of the cladding to be plant-attached to a steel framing system in their fabrication facility. The panel system would allow integration of both the new and restored terra cotta on the same frame, an unprecedented method for this type of project. Such a system reduces the installation schedule as well as improves the over-all quality of the cladding. However, due to the cylindrical shape of the drum and the

Top: Utah State Capitol with drum surrounded by scaffolding.

Bottom: DEA field surveyor laying out grid on drum for tile panel installation.



Plan view of point clouds combined to show entire scan model and radial grid derived from scan data.

“Reestablishing a radial grid in an existing building is a difficult task. Having a point cloud model of the drum and all the columns made it much easier.”

architect’s imperative of a one-quarter inch tolerance, KEPCO+ needed precise as-built information regarding the diameter and shape of the drum to ensure the radial panels would align properly and maintain the drum’s original historic dimensions.

Bruce Knaphus of KEPCO+ happened to be at the Design Build Institute of America (DBIA) annual conference in Orlando, Florida, where Tom Service, LS, from DEA was giving a presentation on laser scanning. Bruce decided to sit in on Tom’s presentation to see if laser scanning could help him with the as-builts for the Capitol Dome project. After the presentation, Bruce spoke to Tom about these challenges, and when Tom returned to Seattle, he asked me to go to Salt Lake City to meet with Bruce and take a look at the project. I needed to determine KEPCO+’s needs and assess the best way to complete the work.

I flew to Salt Lake and met with Bruce and the KEPCO+ design and construction team and toured the project site to see what we were up against. The design team had determined that they needed to reestablish the original radial grid used to construct the drums. Additionally, they needed to locate the horizontal and vertical positions of more than 400 planned core locations, column locations and sizes, and the elevation and location of all window openings, hand rails, and the three terra-cotta veneer rings - all within a quarter-inch relative accuracy.

The site itself presented even more challenges. We needed to bring the

Narrow staircase between inner and outer drum walls is the only access to upper and lower drum.

survey control on the ground very accurately up to the rooftop, but the 10-foot tall parapet walls surrounding the roof made direct traverse from the ground impossible. The roof was divided into four areas with the parapet walls around the perimeters. This configuration made it impossible to run a traverse around the roof. Since we would have to perform the work from the roof, we could not get very far away from the drum, which was considerably higher than the roof, making the angle at which we would be sighting the drum fairly steep.

I returned to Seattle to put together a proposal. I determined that we would perform the work using a combination of conventional survey methods and laser scanning survey methods. I chose to use scanning because I knew it was the best method for obtaining a very accurate detailed model of the existing drum and surrounding architecture, and would allow us to mine additional data from the point clouds as the needs of the client evolved. We would need to use conventional methods to locate some of the core locations because some were positioned in areas where the scanner could not gather data. Conventional methods were also used to perform the control work.

KEPCO+ accepted our proposal. They wanted us to get going immediately because scaffolding was being erected around the entire drum, and if we waited until it was completed, the survey work would be considerably more difficult and time consuming. DEA quickly mobilized a crew out of Denver, our closest office to the project. Once our two-person survey crew, led by Vern Lee, LSIT, arrived on site and had taken the necessary safety orientation classes, they began to tackle the challenging control work.

Vern was provided values for the existing survey control, which was established by the on-site construction surveyors. We ran a traverse on the ground around the building using our Leica TCRA 1103 robotic total station. We turned four sets of angles at each traverse point to keep the control as tight as needed. There were no opportunities for cross ties to strengthen the traverse. We used LISCAD's least squares adjustment program to adjust the horizontal component of the survey control.

"...we could provide measurements to near 95 percent of the drum architecture without returning to the site."

At first, we attempted to constrain our traverse to several of the existing control points around the site, but this didn't work well enough for us to maintain our one-quarter inch specification. To meet the accuracy requirements we could only hold a couple of the existing control points to get onto the project coordinate system and basis of bearing, and then constrain our traverse within itself.

Once we had solid control around the perimeter of the building, we began to transfer the control up to the rooftop where we would be working. Since we could not see the rooftop from the ground, or see between the four separate rooftop areas, we had to complete this segment with open traverses. The fact that we had very tight accuracy requirements, and could not directly tie our control on the roof together, meant we would need to turn additional sets of angles and measure the traverse leg distances multiple times to gain the needed confidence in the control.

We turned eight sets of angles at every traverse point. The traverses were run from the ground up to the walkway around the upper drum, and from there down to the rooftop. We did this on all four sides of the building. After the horizontal component of the control was worked out, we ran a differential level loop up the building staircase around the very narrow and steep staircase that circles the drum and finally to the rooftop and through all of our control points. Then back down!

Once Vern had tight control established, it was time for him and his instrument man, Eric Mena, to start gathering the data that KEPCO+ needed. We had to scan from eight different positions in order get the necessary data and core locations behind the columns on the lower drum. We scanned from two different angles on all four sides of the roof using a Leica HDS 2500 laser scanner. At each scan position KEPCO+ erected 12-foot-tall scaffolding platforms for us to work from. The higher scanner setups enabled us to reduce the vertical angle to the area we were scanning. This allowed us to capture as much data as possible with as little shadowing created by the walkways around the upper and lower drums. Each scan location required about four hours of work.

From each position, we ran a high-density scan on the entire drum to capture the whole area in a single scan, and then we completed several smaller high-density scans to capture as many of the core locations as possible. Due to the accuracy requirements, we chose to include six or more scan targets in each scan. To complete the set-up, we located our scan targets and any core locations that could not be seen from the scanner with our total station. We fashioned our rod with a right-angle mount to allow us to locate the core locations as they were cemented to the wall.

The drum was still covered in the original plaster, and the tile panels could not be mounted to the plaster, so eventually all of the plaster would have to be stripped away from the concrete underneath. What the designers really needed to know was the exact location of the concrete under the plaster.

Due to the tight construction schedule, we could not wait until after the plaster had been stripped to scan the structure. KEPCO+ took random samples to determine the plaster thickness, and it was discovered that the thickness varied throughout. Ultimately, KEPCO+ decided to core through the plaster in nearly 450 locations to measure how the concrete surface below related to the plaster surface above.

At the time we performed our survey, targets were cemented to the plaster at each proposed core location, and each position was assigned a number that corresponded to its location in the radial grid system and elevation on the building. After we had completed the scanning work and gone home, inmates

Upper and lower drums surrounded by scaffolding just prior to tile installation.

from the local penitentiary were brought in to do the coring and measure the plaster thicknesses. This information was then provided to us for inclusion in tabular format on our as-built plan set.

It took our crew four very long days to complete the field work. We performed the work at the end of November so the daylight hours were short, conditions were cold and a little snowy, and we worked well into the dark every day to meet the tight schedule.

Vern brought all the data back to Denver for processing and generating the deliverables. We used the many architectural features, including columns and ornate festoons, to our advantage to supplement the scan targets and help constrain the scan data together very accurately. We used the core targets we had located conventionally to confirm that we had translated the scan data onto the project coordinate system as accurately as needed.

Reestablishing a radial grid in an existing building is a difficult task. Having a point cloud model of the drum and all the columns made it much easier. It gave us the peace of mind that, yes we did have the grid in the best location possible. We used the capabilities of Leica's Cyclone scanning and modeling software to determine the best fit cylinders for the upper and lower drums, which we found had been constructed in extraordinary alignment considering the time. The original surveyors had done an astonishing job with their control and propagating the building grid system as the structure went up. We established the center of the radial grid with our best-fit cylinders of the upper and lower drum. We then established the radial grid lines by holding the center of the north column and arraying that line around the center point at the proper angle. The calculated grid lines were then compared to the existing column center points and found to fit incredibly well. The worst comparison was less than half an inch out, once again a testament to the very accurate work of the original surveyors and constructors.

Although we had used high-tech means of collecting the information in a three-dimensional format, the design team needed traditional two-dimensional as-built plan drawings. We needed to get the information onto paper in an understandable and usable format, both graphically and tabularly.

Vern generated tables for the core locations and plaster thicknesses, and the window elevations and dimensions. Plan view sections, or slices, were created for the terra-cotta veneer rings at specified elevations on the drum and showed the handrails and columns. Elevations and dimensions from the center of the radial grid to the plaster face and center of columns were shown on the plan view sections. Elevation views were created to show the section elevations, and column dimensions. Vern produced all of the data and drawing files in Denver and sent them to me in Seattle, where Tom and I reviewed them before sending them back to KEPCO+ in Salt Lake City.

As KEPCO+ progressed through the design process, and began to see the product coming in from DEA, they started to determine all of the other information that they would like to have for their design work. This is when our choice to use laser scanning really paid off. Since we had scanned the site, we could provide measurements to near 95 percent of the drum architecture without needing to return to the site. We ended up with five requests for additional information, each with several tasks. The plans went from a seven-sheet as-built plan set to 19 sheets. We created several more sheets of sections and required dimensions. If we had chosen to use our total station to locate the data that the design team was requesting we would not have been able to complete any of the additional information requests without returning to the project site to collect the data, and the laser scanning did not increase our initial field effort significantly, if at all.

Fast forward 10 months. The project had been completed from our perspective. KEPCO+ had what they needed from us. Then, seemingly out of the blue, I received a call from Jacobsen Hunt, Joint Venture in Salt Lake City. Jacobsen Hunt was the construction contractor on the Capitol renovation work.

Jacobsen Hunt was at the point where they were laying out gridlines

HDS 2500 atop scaffolding platform which was used to reduce the vertical angle for scanning the drum.

and elevations on the drum so they could mount the tile panels, install new columns, and perform the rest of the work on the drum. Their surveyors had brought the building grid and elevation up from their ground control several ways and were not getting anything to come together better than an inch. This was not a surprise to me. I remembered the problems we had trying to constrain to several of the existing control points when we ran our control.

They went on to tell me that all of our ground control in the area had been wiped out during the site work, and were not sure if any of our rooftop control points still existed or were accessible. Jacobsen Hunt wanted DEA surveyors to come to the site for a week and get the necessary layout work done, and they wanted us there as soon as possible. We would need to get the radial grid laid out on the face of the drum and offset onto the steel framework they had erected around the drum, and establish several benchmarks throughout the work area.

If our control on the rooftop was destroyed or inaccessible we would have to use coordinates generated from architectural features found in the scan data and still visible on the drum and dome of the building to resection in new rooftop control points in order to meet the one-quarter of an inch accuracy requirements. With the control on the ground being reestablished from points at the exterior of the Capitol Campus, we would not be able to bring up control from the new ground control. This was not going to be a simple task.

At this point, Vern was working in DEA's Ontario, California office. He quickly grabbed two highly experienced survey and building layout crew members and drove to Salt Lake City to get the layout work accomplished.

Jacobsen Hunt let us set up a workstation in their job trailer. We took the necessary safety orientation classes, and started to look for our old rooftop control. We were very lucky to find all of it. We still wanted to make sure it had not moved with any of the seismic isolation work or other construction activities that had gone on since we were last on site. We located several architectural features just below the drum and on the dome with our total station to compare our shots with the values derived from the scan data on these same points a year ago. Our check shots fit very well. We were well within the required one-quarter of an inch relative accuracy and many of the check shots were closer to one-sixteenth of an inch. Because we had Vern in the job trailer to perform the needed calculations, and were able to recover all of our control (and it checked out so well), with a highly experienced layout crew on the job, we were able to take care of all of the contractor's needs.

Work on the Capitol Campus project continues. The drum tiling has been completed, the columns are installed, and new hand rails have been mounted. The building looks beautiful and will soon be fully equipped to function into the 22nd Century, and I'm proud to say DEA was a part of the team that made it happen.

Sean Douthett is a senior associate and survey discipline leader for David Evans and Associates, Inc.'s Tacoma, Washington office. He has more than 16 years of professional experience, and is licensed in Washington.